Name ____ AP Chemistry

Introduction to Acids & Bases

Part I: Definitions of Acids & Bases

Acids and bases play an important role in our lives. Numerous biological processes, industrial applications, and even environmental problems are a function of the acidity or basicity (alkalinity) of aqueous solutions. It is therefore important to understand what makes a substance behave as an acid or a base when dissolved in water. There are three different ways to define a substance as an acid or base. One definition is based on the ions found in a compound (Arrhenius), another is based on how a compound behaves when added to water (Bronsted-Lowry), and a third is based on how a molecule reacts with other molecules (Lewis). These definitions address different behaviors of compounds and explain how seemingly different compounds can be classified as behaving like an acid or a base.

Model #1: Arrhenius Acids and Bases

Common Name for Aqueous Solution	Chemical Formula	Found in…	Tastes…	Turns Litmus Paper…	Conducts Electricity?	Acid or Base
Acetic acid	$HC_2H_3O_2$	Vinegar	Sour	Red	Yes	Acid
Benzoic acid	$HC_7H_5O_2$	Food preservative	Sour	Red	Yes	Acid
Phosphoric acid	H_3PO_4	Soda pop	Sour	Red	Yes	Acid
Hydrochloric acid	HCl	Stomach acid	Sour	Red	Yes	Acid
Citric acid	$H_3C_6H_5O_7$	Citrus fruits	Sour	Red	Yes	Acid
Ascorbic acid	$H_2C_6H_6O_6$	Vitamin C	Sour	Red	Yes	Acid
Magnesium hydroxide	$Mg(OH)_2$	Milk of magnesia	Bitter	Blue	Yes	Base
Aluminum hydroxide	$Al(OH)_3$	Antacids	Bitter	Blue	Yes	Base
Barium hydroxide	$Ba(OH)_2$	Lubricants	POISON	Blue	Yes	Base
Sodium hydroxide	$NaOH$	Drain cleaner	POISON	Blue	Yes	Base

1) (a) Examine the properties of the Arrhenius acids in Model #1. Name three properties they have in common.
(b) Examine the chemical formulas of these acids. What feature do all the formulas have in common?

2) (a) Examine the properties of the Arrhenius bases in Model #1. Name two properties they have in common.
(b) Examine the chemical formulas of these bases. What feature do all the formulas have in common?

> In 1903 Svante Arrhenius won the Nobel Prize in Chemistry for defining acids and bases in terms of the ions produced. An Arrhenius acid is any substance that produces hydrogen ions [or hydronium ions (H_3O^+) a hydrogen ion attached to a water molecule] when dissolved in water. An Arrhenius base is any substance that produces hydroxide ions when dissolved in water. While the Arrhenius definitions of acids and bases are useful, it is limited. Johannes Bronsted and Thomas Lowry developed more general definitions for acids and bases using H+ ion (proton) transfer as the focus.

<u>Model #2: Bronsted-Lowry Acids and Bases</u>

Reaction 1	$HCl(g)$ (acid)	+	$H_2O(l)$ (base)	$\rightleftarrows$	$H_3O^+(aq)$ + $Cl^-(aq)$
Reaction 2	$NH_3(aq)$ (base)	+	$HF(aq)$ (acid)	$\rightleftarrows$	$NH_4^+(aq)$ + $F^-(aq)$
Reaction 3	$NH_4^+(aq)$ (acid)	+	$H_2O(l)$ (base)	$\rightleftarrows$	$NH_3(aq)$ + $H_3O^+(aq)$
Reaction 4	$F^-(aq)$ (base)	+	$H_2PO_4^-(aq)$ (acid)	$\rightleftarrows$	$HPO_4^{2-}(aq)$ + $HF(aq)$

3) Looking at the acid-base reaction in Model #2, describe the role of the Bronsted-Lowry acid in the H^+ ion (proton) transfer that occurs.

4) Looking at the acid-base reaction in Model #2, describe the role of the Bronsted-Lowry base in the H^+ ion (proton) transfer that occurs.

5) As you saw in Model #1, all Arrhenius bases in Model 1 have an OH– ion in their chemical formulas. Write a balanced chemical reaction for the reaction of HCl (aq) with OH^-(aq) to illustrate that the hydroxide ion is also a Bronsted-Lowry base.

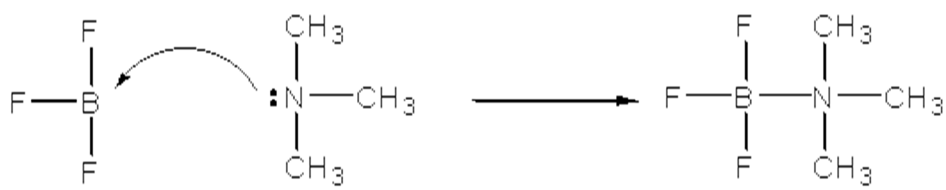
6) Write the reverse reaction for Reactions 1-3. Label the Bronsted-Lowry acid and base in the reactants for each reaction.
   (a) Reaction 1

   (b) Reaction 2

   (c) Reaction 3

A more general model for acid-base behavior was suggested by G.N. Lewis in the early 1920s. A Lewis acid is an electron-pair acceptor, and a Lewis base is an electron-pair donor. Another way of saying this is that a Lewis acid has an empty atomic orbital that is can use to accept (share) an electron pair from a molecule that has a lone pair of electrons (Lewis base).

Model #3: Lewis Acids and Bases



7) Identify the Lewis acid and base in Model #3.

8) Identify the Lewis acid and the Lewis base in each of the following reaction
   (a) $B(OH)_3$ (aq) + H_2O (l) ↔ $B(OH)_4^-$ (aq) + H^+ (aq)

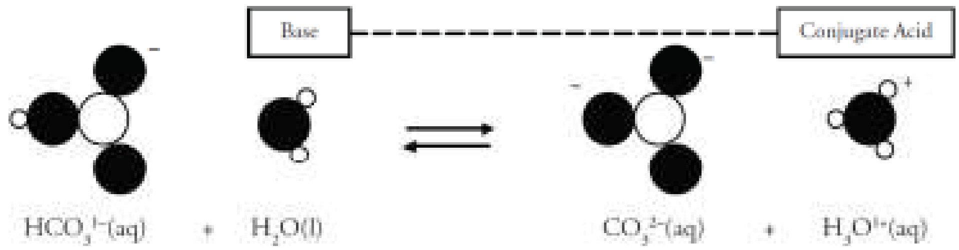
   (b) Ag^+ (aq) + 2 NH_3 (aq) ↔ $Ag(NH_3)_2^+$ (aq)

   (c) BF_3 (g) + F^- (aq) ↔ BF_4^- (aq)

Summary Table

Model	**Definition of Acid**	**Definition of Base**
Arrhenius	H^+ producer	OH^- producer
Bronsted-Lowry	H^+ donor	H^+ acceptor
Lewis	Electron-pair acceptor	Electron-pair donor

Model #4: Conjugate Acid-Base Pairs



9) All acid-base reactions have two conjugate acid-base pairs. One conjugate acid-base pair in the reaction in Model #3 is H_3O^+/H_2O. List the other acid-base pair in the reaction.

10) Which species is the acid in the second acid-base pair and which species is the base? Why?

11) Using the list of substances below, select pairs that are conjugate acids and bases. Enter the pairs in the tables below. The first acid-base pair has been entered for you. Note that you may use a substance more than once or not at all.

H_3PO_4
H_2O
$HC_2H_3O_2$
H_3O^+

NH_2^-
PO_4^{3-}
NO_2^-
CO_2

HPO_4^{2-}
$C_2H_3O^{2-}$
CO_3^{2-}
OH^-

H_2CO_3
NH_3
$H_2PO_4^-$

Acid	**Conjugate Base**	**Acid**	**Conjugate Base**
H_3PO_4	$H_2PO_4^-$		

12) Water is an amphoteric substance, meaning it can behave as both an acid and a base. Write a chemical reactions showing water as an acid and then as a base.

Part II: Strength of Acids & Bases

When you hear an acid called "strong" or "weak", what do those terms refer to? In aqueous solutions, compounds can exist as molecules (undissociated) or ions (dissociated).

When an acid or a base exists in solution nearly completely as dissociated ions, we refer to that acid or base as strong. A weak acid or base will donate ions to the solution, but will remain primarily as undissociated molecules.

Acids are abbreviated HA with the H representing the proton (H^+) the acid donates to the solution. The A is referred to as the acidic anion (A^-) that is left in solution as the proton is donated:

$$HA \leftrightarrow H^+ + A^-$$

Bases are abbreviated MOH with the OH representing the hydroxide ion (OH^-) the base donates to the solution. The M is cation (M^+) that is left in solution as the hydroxide is donated:

$$MOH \leftrightarrow M^+ + OH^-$$

Model #5: Acid-Base Solutions PhET

13) Go to http://phet.colorado.edu. Click on "Play With Sims," then "Chemistry" on the left side bar, then find and click on "Acid-Base Solutions," and finally click "Run Now!"
14) Begin with 'Strong Acid' on the 'Introduction' tab. Make sure that 'Molecules' is chosen under Views and 'pH meter' under Tests. Draw an image of the beaker in the appropriate box below and record the pH of the solution by lowering the pH meter into the solution.
15) Repeat with 'Weak Acid,' 'Strong Base,' and 'Weak Base.'

Strong Acid	**Weak Acid**
Strong Base	**Weak Base**

16) Switch to the 'Custom Solution' tab. Choose 'Equilibrium Concentration' under the Views section and 'pH meter' under Tests section.

17) Complete the following tables by changing the 'Initial Concentration' under the Solution section. Make sure to choose 'acid' or 'base' and 'weak' or 'strong' under the Solution section based on the appropriate table.

	Initial Concentration (M)	**[HA] (M)**	**$[A^-]$ (M)**	**$[H^+]$ (M)**	**pH**
Strong Acid	0.010				
	0.050				
	0.100				
	1.00				

	Initial Concentration (M)	**[HA] (M)**	**$[A^-]$ (M)**	**$[H^+]$ (M)**	**pH**
Weak Acid	0.015 (weaker)				
	0.150 (weaker)				
	0.015 (stronger)				
	0.150 (stronger)				

	Initial Concentration (M)	**[MOH] (M)**	**$[M^+]$ (M)**	**$[OH^-]$**	**pH**
Strong Base	0.010				
	0.050				
	0.100				
	1.00				

	Initial Concentration (M)	**[B] (M)**	**$[BH^+]$ (M)**	**$[OH^-]$**	**pH**
Weak Base	0.015 (weaker)				
	0.150 (weaker)				
	0.015 (stronger)				
	0.150 (stronger)				

Electrolytes are substances that dissolve in water to produce ions in solution. The presence of ions allows a solution to conduct an electrical current. Ions may be produced because the substance that dissolves is ionic (like salt), or because the substance reacts with water to produce ions (as is the case with acids). The more ions that are formed in solution, the stronger the electrolyte. Nonelectrolytes are substances whose aqueous solutions do not contain ions and therefore do not conduct an electrical current.

18) In each of the following statements, circle the appropriate phrase:
   (a) A strong acid is very concentrated/exists primarily as ions.
   (b) A weak base is a nonelectrolyte/weak electrolyte/strong electrolyte.
   (c) A strong base is a nonelectrolyte/weak electrolyte/strong electrolyte.

(d) At the same concentration (Molarity) a strong acid will have a <u>higher/lower/the same</u> pH as a weak acid.

(e) As concentration of a weak acid increases, the pH <u>increases/decreases/remains constant</u>.

(f) As concentration of a weak base increases, the pH <u>increases/decreases/remains constant</u>.

(g) As the concentration of a weak acid increases, the number of ions <u>increases/decreases/remains constant</u>.

(h) As the strength of a weak acid increases, the proportion of ions to molecules <u>increases/decreases</u>.

<u>Model #6: The Meaning of K_a and K_b</u>

HA (aq) + H_2O (l) ↔ H_3O^+ (aq) + A^-(aq) $$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

B^- (aq) + H_2O (l) ↔ HB (aq) + OH^- (aq) $$K_b = \frac{[HB][OH^-]}{[B^-]}$$

K_a and K_b Values

Name of Acid	Acid	K_a	Name of Base	Base	K_b
Sulfuric acid	H_2SO_4	large	hydrogen sulfate ion	HSO_4^-	very small
Hydrochloric acid	HCl	large	chloride ion	Cl^-	very small
Nitric acid	HNO_3	large	nitrate ion	NO_3^-	very small
Hydronium ion	H_3O^+	55.5	water	H_2O	1.8×10^{-16}
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	sulfate ion	SO_4^{2-}	8.3×10^{-13}
Phosphoric acid	H_3PO_4	7.5×10^{-3}	dihydrogen phosphate ion	$H_2PO_4^-$	1.3×10^{-12}
Hexaaquairon(III) ion	$Fe(H_2O)_6^{3+}$	6.3×10^{-3}	pentaaquahydroxoiron(III) ion	$Fe(H_2O)_5OH^{2+}$	1.6×10^{-12}
Hydrofluoric acid	HF	7.4×10^{-4}	fluoride ion	F^-	1.4×10^{-11}
Formic acid	HCO_2H	1.8×10^{-4}	formate ion	HCO_2^-	5.6×10^{-11}
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	benzoate ion	$C_6H_5CO_2^-$	1.6×10^{-10}
Acetic acid	CH_3CO_2H	1.8×10^{-5}	acetate ion	$CH_3CO_2^-$	5.6×10^{-10}
Hexaaquaaluminum ion	$Al(H_2O)_6^{3+}$	7.9×10^{-6}	pentaaquahydroxoaluminum ion	$Al(H_2O)_5OH^{2+}$	1.3×10^{-9}
Carbonic acid	H_2CO_3	4.2×10^{-7}	hydrogen carbonate ion	HCO_3^-	2.4×10^{-8}
Hydrogen sulfide	H_2S	1×10^{-7}	hydrogen sulfide ion	HS^-	1×10^{-7}
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	hydrogen phosphate ion	HPO_4^{2-}	1.6×10^{-7}
Hypochlorous acid	HClO	3.5×10^{-8}	hypochlorite ion	ClO^-	2.9×10^{-7}
Ammonium ion	NH_4^+	5.6×10^{-10}	ammonia	NH_3	1.8×10^{-5}
Hydrocyanic acid	HCN	4.0×10^{-10}	cyanide ion	CN^-	2.5×10^{-5}
Hexaaquairon(II) ion	$Fe(H_2O)_6^{2+}$	3.2×10^{-10}	pentaaquahydroxoiron(II) ion	$Fe(H_2O)_5OH^+$	3.1×10^{-5}
Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	carbonate ion	CO_3^{2-}	2.1×10^{-4}
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	phosphate ion	PO_4^{3-}	2.8×10^{-2}
Water	H_2O	1.8×10^{-16}	hydroxide ion	OH^-	55.5
Hydrogen sulfide ion	HS^-	1×10^{-19}	sulfide ion	S^{2-}	1×10^{5}

19) Is K_a and K_b similar to K? Explain why or why not.

20) For each of the following strengths of acid or base, decide if K_a or K_b is greater or less than 1?

(a) Strong acid: K_a

(b) Weak acid: K_a

(c) Strong base: K_b

(d) Weak base: K_b

21) Locate acetic acid on the table below and record the K_a below. Then locate the acetate ion and record the K_b below. Then multiply K_a and K_b together.

22) K_a and K_b multiplied together is known as the autoionization of water. What is its value?

*Adapted from “Introduction to Acids and Bases” by Josephine Parlagreco and Robert Dayton (Stony Brook University), “Acids and Bases” from POGIL™ Activities for High School Chemistry, “Strong versus Weak Acids” from POGIL™ Activities for High School Chemistry, and “Introduction to Strong and Weak Acids and Bases PhET Lab” by Chris Bires (http://phet.colorado.edu/en/contributions/view/3306).